by LERBOR

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Practical experiments are not just motivational
and fun: they can also sharpen students
powers of observing and questioning
and are key to enhanced learning

Experiment Manual

ELECTRICITY & MAGNETISM Kit

Thinking, Observing, Questioning and Experimenting

Science Action Labs
Hands-on Physics Experiments
Learning by Doing

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Contents in Brief

ELECTRICITY

CHAPTER 1

1 Get a lightbulb to light

*Any closed loop or conducting path allowing electric charges to flow is called an **electric circuit**. In this experiment, you will investigate conditions that create current in an electric circuit.*

QUESTIONS ***Can you get the bulb to light with a battery, a lightbulb and a wire?***

Objectives

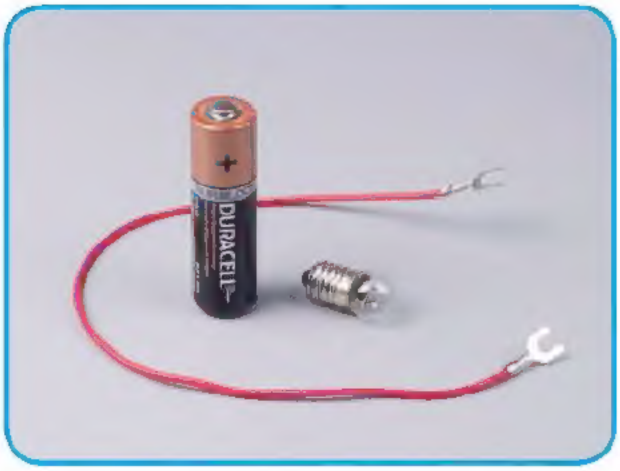
Describe conditions that create current in an electric circuit.

Precautions

Wire and lightbulbs can be hot if connected across the battery for a long time. DO NOT connect the wire directly across the battery without any appliance. This will possibly destroy the battery.

Materials

one 1.5-V battery (AA battery)
one Lightbulb
one Wire



Procedures

1. Try to find as many ways as possible to get the lightbulb to light.
2. Diagram two ways in which you are able to get the lightbulb to work.
3. Diagram at least three ways in which you are not able to get the bulb to light.

Analyzes

4. How did you know if electric current was flowing?
5. What do your diagrams of the lit bulb have in common?
6. What do your diagrams of the unlit bulb have in common?
7. From your observations, what conditions seem to be necessary in order for the bulb to light?

Conclude & Apply

Summarize the conditions that create current in an electric circuit.

Chapter 1

Current & Circuits

Two ways to get the lightbulb to work:

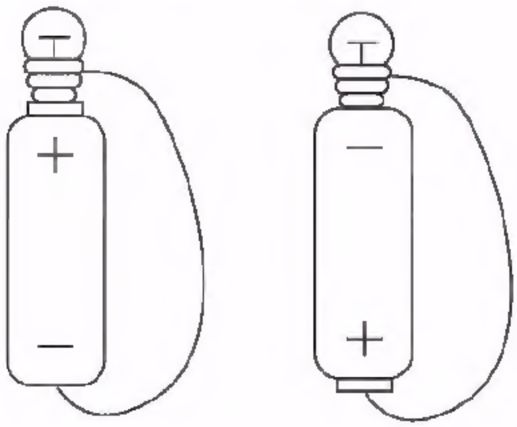


Figure 1-1

Electric Current

A flow of charged particles is an electric current. We conventionally use I *(short for intensity)* to represent the current. The current, I, is measured in amps. The unit for current is named after French scientist *Andre-Marie Ampère*.

An object can store energy as the result of its position. For example, a heavy ball is storing energy when it is held at an elevated position. This stored energy of position is referred to as potential energy. When you release the ball from a certain height above the ground where the potential is higher, it will drop automatically to the ground where the potential is lower.

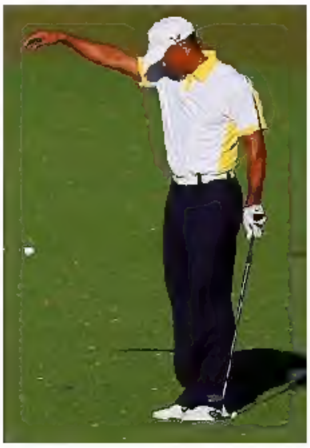


Figure 1-2
(Ball drops automatically from high potential position to low potential one)

Similarly, charges flow from the conductor at a higher potential to the one at a lower potential. The flow continues until there is no potential difference between the two conductors.

In Figure 1-3a, two conductors, A and B, are connected by a wire conductor, C. Charges flow from the higher potential difference of B to A through C. The flow stops when the potential difference between A, B, and C is zero. You could maintain the electric potential difference between B and A by pumping charged particles from A back to B, as illustrated in Figure 1-3b.

The charges in Figure 1-3b move around a closed loop, cycling from the pump to B, through C, to A and back to the pump. Any closed loop or conducting path allowing electric charges to flow is called an electric circuit.

An electric circuit includes a charge pump (in this experiment, the battery), which increases the potential energy of the charges flowing from A to B, and a device (in this experiment, the lightbulb) that reduces the potential energy of the charges flowing from B to A, and of course conductors (in this experiment, the wire) which allow the charges to flow.

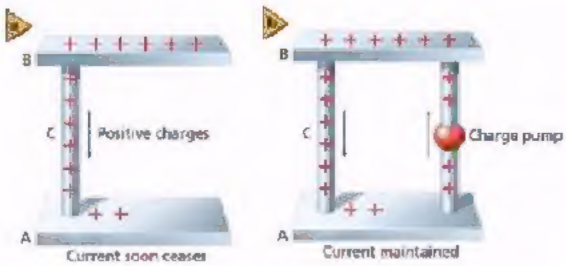


Figure 1-3
(Conventional current is defined as positive charges flowing from the positive plate to the negative plate (a).

A generator pumps the positive charges back to the positive plate and maintains the current (b).

In most metals, negatively-charged electrons actually flow from the negative to the positive plate, creating the appearance of positive charges that are moving in the opposite direction.)

CHAPTER 2
2 Series Circuits & Parallel Circuits

There is a series circuit and a parallel circuit in the Figure below. Could you tell the difference between them? In this experiment you will learn about Series Circuits and Parallel Circuits.

QUESTIONS ***What will happen if you turn on and off a switch in a series circuit and a parallel circuit?***

Objectives

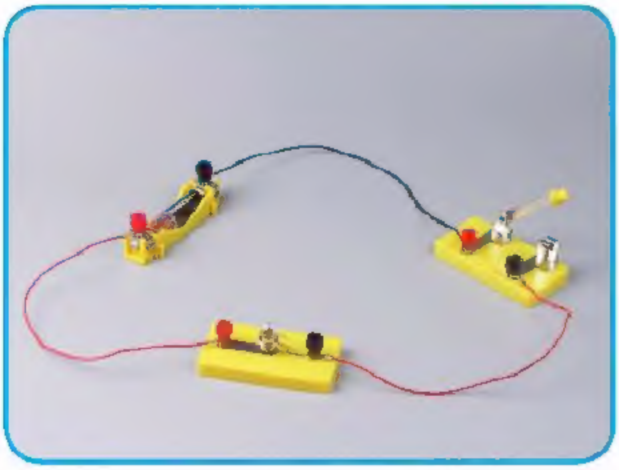
Define series circuits and parallel circuits.
Describe how switches affect the series circuits and parallel circuits.

Precautions

Wire and lightbulbs can be hot if connected across the battery for a long time.

Materials

one 1.5-V battery
two Lightbulbs
two Lightbulb sockets
two Switches
some Wires



Procedures

Experiment A

1. Connect the positive terminal of a battery to one terminal of a lightbulb.
2. Connect the other terminal of the lightbulb to one terminal of a switch.
3. Connect the other terminal of the switch to the negative terminal of the battery.
4. **Observe** Make observations of the lightbulb when the switch is turned on and off.

Experiment B

5. Hook up a circuit in the *Experiment A* by repeating step 1~3.
6. Connect one terminal of a lightbulb A to the one terminal of another lightbulb B.
7. Connect the other terminal of the lightbulb B to a terminal of another switch B.
8. Connect the other terminal of the switch B to the other terminal of the lightbulb A.
9. **Observe** Make observations of the lightbulbs when the switches are turned on and off in the experiments.

Analyzes

10. Which kind of circuit you were hooking up in each of the experiments? A series circuit or a parallel circuit?
11. How did the current flow in each circuit in the experiments?
12. What happened to the lightbulbs when the switches are turned on and off? Try to explain.

Conclude & Apply

Summarize the difference between series circuits and parallel circuits.

Going Further

Try to list some applications of the series circuit and parallel circuit in daily life.

Chapter 2

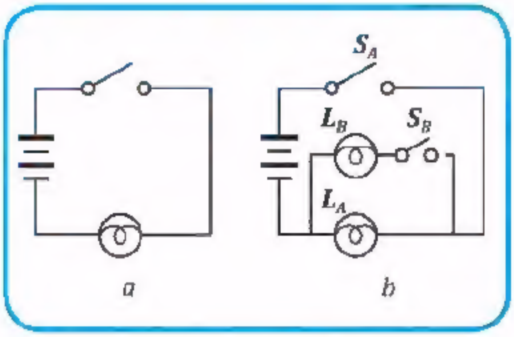


Figure 2-1

Series Circuits

A circuit like the one in *Figure 2-1a*, in which all current travels through each device, is called a series circuit. If the circuit become open when the switch is turned off or the filament inside the lightbulb get burned and become no longer connected, the current stops flowing.

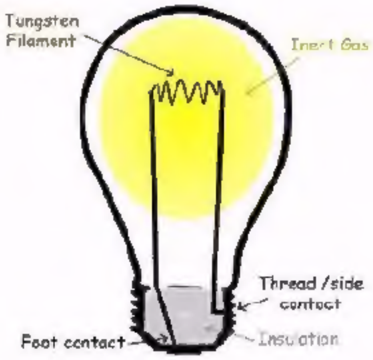


Figure 2-2
(Filament heats up when an electric current passes through it and produces light as a result.)

Parallel Circuits

A circuit like the one in *Figure 2-1b*, in which there are several current paths is called a parallel circuit. The current from power supply goes through both lightbulbs. When you turn off the switch B, the current through the lightbulb B stop flowing, which cause the lightbulb B not working anymore. On the other hand, the lightbulb A will still be lighting because it is still a close loop and the current through it didn't stop flowing.

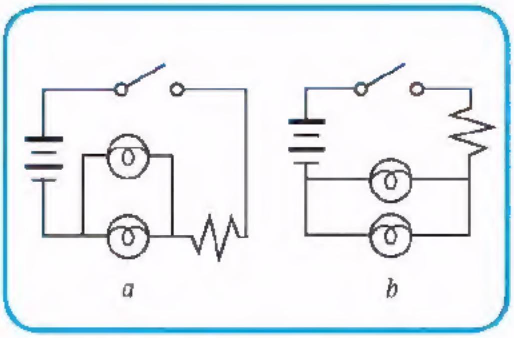


Figure 2-3

Can you tell whether the circuit in *Figure 2-3a* is a series circuit or a parallel circuit? There are two lightbulbs connected in parallel while a third lightbulb is in series with the parallel circuit. Such a circuit, which includes series and parallel branches, is called a combination series-parallel circuit. The diagram of this circuit can also be drawn as *Figure 2-3b*.

Real-World Physics

The lightbulbs on a Christmas tree are usually in series.

Street lights are usually in parallel.

CHAPTER 3

3 Use of an ammeter

An ammeter is a device that is used to measure the current.
In this experiment, you will learn how to measure the current with an ammeter.

QUESTIONS ***Can you measure the current with an ammeter?***

Objectives

Summarize how to measure the current in an electric circuit using an ammeter.
Describe how to read the current on an ammeter.

Precautions

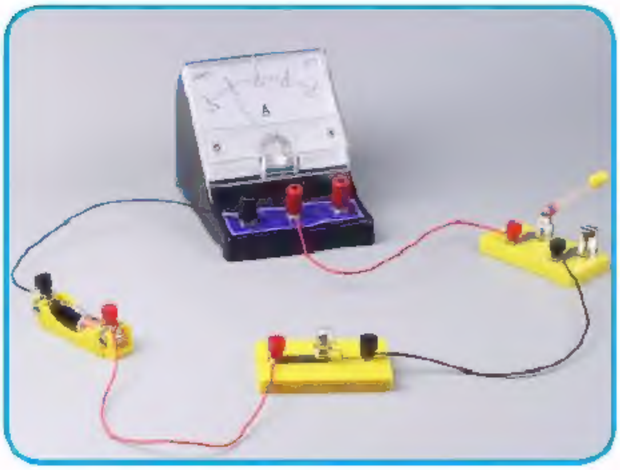
Wire and lightbulbs can be hot if connected across the battery for a long time.

DO NOT connect the ammeter directly across the battery without any appliance. This will possibly damage the ammeter, destroy the battery and even cause a fire.

Make sure the pointer of the ammeter is at zero, or you have to rotate the white screw to make it point at zero.

Materials

one 1.5-V battery	one Ammeter
one Lightbulb	one Lightbulb socket
one Switch	some Wires



Procedures

Experiment A

1. Connect the positive terminal of a battery to one terminal of a lightbulb.
2. Connect the other terminal of a lightbulb to one terminal of a switch.
   Make sure the switch is open (turned off).
3. Connect the other terminal of the switch to one of the positive terminal of an ammeter, "0.6A".
4. Connect the negative terminal of an ammeter, "-", to the negative terminal of the battery.
5. **Observe** Close the switch (turned on) and make observations of the ammeter.

Experiment B

6. Connect the positive terminal of a battery to the other positive terminal of an ammeter, "3A", in step 3 and repeat step 1–5. Predict what will happen on the ammeter after the switch was closed.

Analyzes

7. When you connect the "0.6A" terminal, what is the smallest scale (current between 2 closest lines)? What about when you connect the "3A" terminal?
8. What is the reading of the current in each experiment?
9. How do you read the current on an ammeter?
10. Is the current in both experiments the same?
11. *0.6A* and *3A* are two different ranges of the ammeter, which means the maximum current you can measure. Which range do you think is most appropriate to use? Why?

Conclude & Apply

Summarize how to measure the current in an electric circuit using an ammeter.
Describe how to read the current on an ammeter

Chapter 3

Ammeter

1. The ammeter should be connected in the circuit in series. Don't connect the ammeter in parallel across an element. (You will learn the reason in *Chapter 7*)

2. You must ensure that the line of sight is perpendicular to the scale of the ammeter. As shown in *Figure 3-1*, the correct reading should be 0A but if you read the current when the line of sight is not perpendicular to the scale, a parallax error is committed.

Figure 3-1

3. There are 31 linves on the scale of the ammeter. The smallest scale is 0.02A when you connect the "0.6A" terminal and 0.1A when you connect the "3A" terminal.

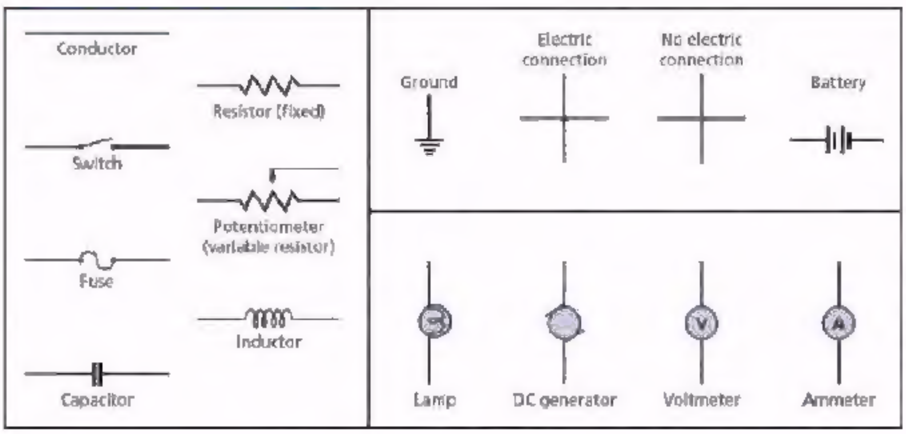
4. If the pointer is not exactly at the lines, we can approximate the reading. For example, in *Figure 3-2*, if the "0.6A" terminal is connected, reading of the current can be approximated as 0.15A.

Figure 3-2

5. You can read the current more preciously when you choose the smaller range. But you have to make sure the current will too big for the range you choose.

The resistance of the ammeter is very small, so when the ammeter is added in the circuit, the current barely changes. Because only the range is different in each experiment, the current remains nearly the same.

Circuit Diagram



An electric circuit is drawn using standard symbols for the circuit elements. Such a diagram is called a circuit diagram or a circuit schematic. Some of the symbols used in circuit schematics are shown in *Figure 3-3*.

Figure 3-3
(These symbols commonly are used to diagram electric circuits.)

CHAPTER 4

Do current diminish as it flows?

What is your prediction about the brightness of the two lightbulbs in the picture below after the circuit is connected? Test your prediction by building the circuits.

QUESTIONS ***Do you think that current diminishes as it passes through different elements in a series circuit?***

Objectives

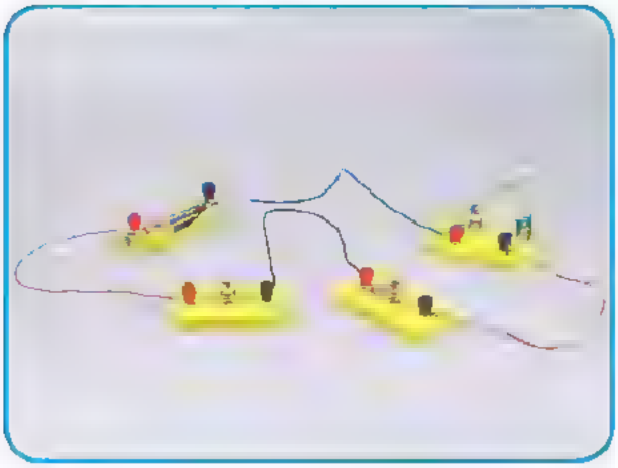
Test if current diminishes as it passes through different elements in the circuit by building the circuits

Precautions

Wire and lightbulbs can be hot if connected across the battery for a long time.
DO NOT connect the ammeter directly across the battery without any appliance.

Materials

one 1.5-V battery
one Ammeter
two Lightbulbs
two Light sockets
one Switch
some Wires



Procedures

1. Draw a circuit that includes a power supply, two identical lightbulbs and a switch.
2. Draw the circuit again and include an ammeter to measure the current between the power supply and the lightbulb.
3. In a third diagram, show the ammeter at a position to measure the current between the lightbulbs.

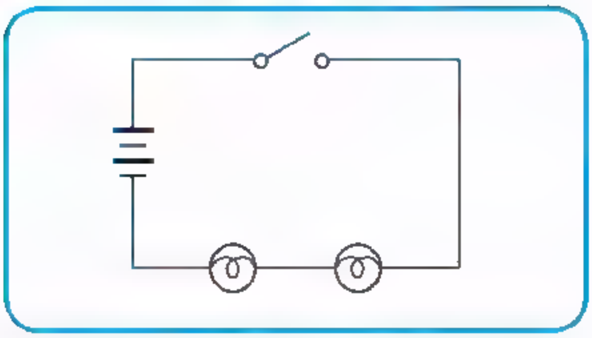
Analyzes

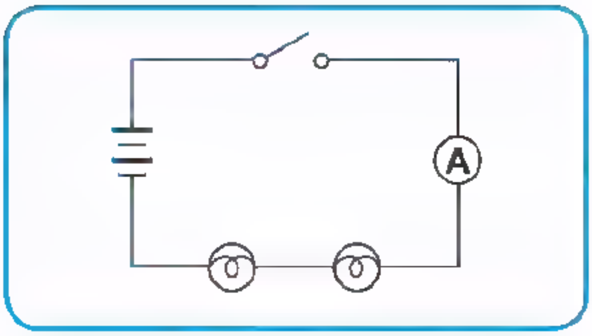
4. Predict if the current between the lightbulbs will be more than, less than, or the same as the current before the lightbulbs. Explain.
5. Test your prediction by building the circuits.

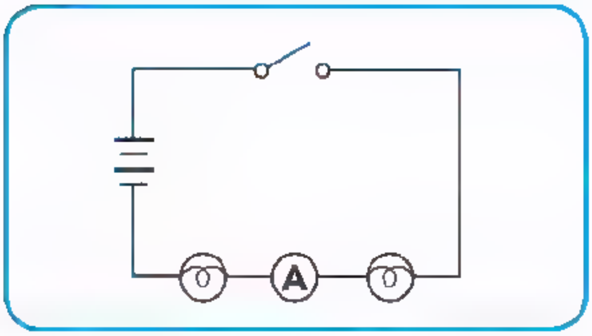
Conclude & Apply

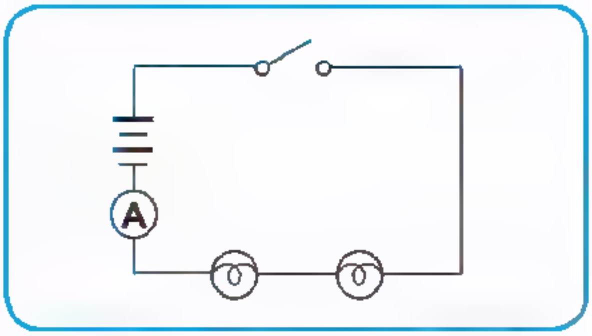
Read the current on each of the ammeter in step 2 & 3
Summarize the characteristics of the current when it flows through a series circuit.

Chapter 4









Prediction 1

The first lightbulb which is close to the positive (+) terminal of the battery will be brighter because a large amount of the current will be used up by the first lamp

Prediction 2

The second lightbulb will be brighter because only part of the current will be used up, and the second lamp will be brighter than the first.

Prediction 3

The brightness of the lightbulbs will be the same because the current will be the same in each lamp

From the result of the experiment, the brightness of the lightbulbs is the same.

We knew that the brightness of a lightbulb depends on the current through it. Charge cannot be created or destroyed. Because the charge in the circuit has only one path to follow and cannot be destroyed, the same amount of charge must leave a circuit as enters the circuit. This means that the current is the same everywhere in the circuit.

CHAPTER 5

5 Resistance

In this experiment, you will learn about the resistance

QUESTIONS ***How resistance affects current in a circuit?***

Objectives

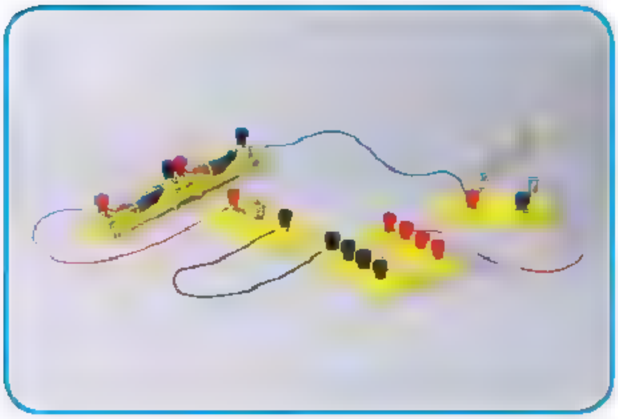
Define resistance.
Describe the effect of resistance on current in a circuit

Precautions

Resistors and circuits will become hot.
DO NOT connect the ammeter directly across the battery without any appliance.

Materials

two 1.5-V batteries
one Ammeter
5-Ω resistor
10-Ω resistor
(A resistor is a device designed to have a specific resistance)
one Lightbulb
one Switch
some Wires



Procedures

1. Draw a circuit that includes a power supply, a lightbulb, a resistor and a switch in series
2. Hook up the circuit using a 5-Ω resistor.
3. Hook up another circuit by replacing the 5-Ω resistor with a 10-Ω resistor.

Analyzes

4. Predict if the lightness of the lightbulb in step 2 will be more than, less than, or the same as the lightness of the lightbulb in step 3. Explain.
5. Test your prediction
6. Insert an ammeter in the circuit and make observation on the current.

Conclude & Apply

Define resistance.
Describe how resistance affects current in a circuit.

Chapter 5

For an electron, the journey from terminal to terminal is not a direct route. Rather, it is a zigzag path that results from countless collisions with fixed atoms within the conducting material. The electrons encounter resistance - a hindrance to their movement While the electric potential difference established between the two terminals encourages the movement of charge, it is resistance that discourages it The rate at which charge flows from terminal to terminal is the result of the combined effect of these two quantities.

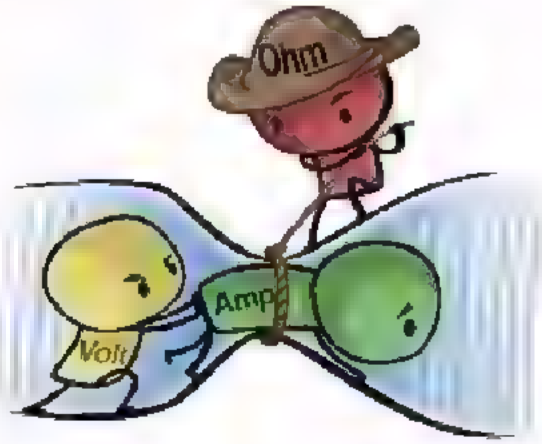


Figure 5-1
(The resistance is a hindrance to the movement of the current)

The resistance of the conductor, *"R"*, is measured in ohms.
The unit for resistance is named after German scientist *Georg Simon Ohm*, who found that the ratio of potential difference to current is constant for a given conductor:

$$\frac{V}{I} = constant$$

Introducing the constant of proportionality, the resistance, *"R"*. We arrives at an equation:

$$R = \frac{V}{I}$$

Resistance is equal to voltage divided by current.

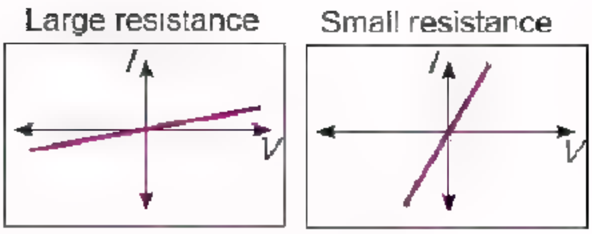


Figure 5-2
(The property determining how much current will flow is called resistance.)

Figure 5-3 lists some of the factors that impact resistance. The type of material affects resistance.

For example, a copper wire has less resistance compared with an iron wire of the same length and diameter *(A)*.

A shorter wire has less resistance than a longer wire of the same diameter that is made from the same material *(B)*

A thicker wire has less resistance than a wire of the same length that is made from the same material *(C)*.

Resistance increases with temperature. A cold filament has less resistance than a hot filament *(D)*.

Figure 5-3(A).

Figure 5-3(B).

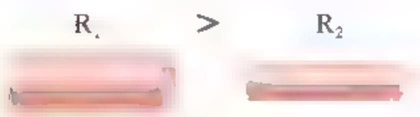


Figure 5-3(C).

Figure 5-3(D).

CHAPTER 6

6 Potentiometer

In this experiment, you will get to know about resistance and potentiometer

QUESTIONS ***What will happen when you move the slider of the potentiometer from one side to another in Figure below?***

Objectives

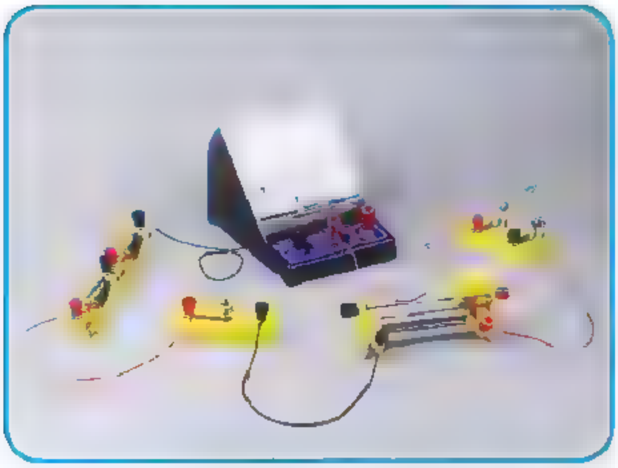
Learn about how to use a potentiometer to affect the current in a circuit.

Precautions

Wire and lightbulbs can be hot if connected across the battery for a long time.

Materials

two Batteries
one Lightbulb
one Switch
one Potent ometer
one Ammeter
some Wires



Procedures

1. Connect the positive terminal of a battery to one terminal of a lightbulb.
2. Connect the other terminal of the lightbulb to the bottom left terminal of a potentiometer
3. Connect the top right terminal of a potentiometer to one terminal of a switch. Make sure the switch is open *(turned off)*
4. Connect the other terminal of the switch to the positive terminal of an ammeter.
5. Connect the negative terminal of the ammeter to the negative terminal of the battery.
6. **Observe** Close the switch *(turned on)* and make observations of the lightbulb and then the ammeter when you move the slider of the potentiometer from one side to another.

Analyzes

7. What happened in the experiment?
8. Connect the bottom right terminal of a potentiometer to one terminal of a switch on step 2 and repeat the experiment. What will happen?
9. Repeat the experiment while changing the wring of the potentiometer. Record the result.

Conclude & Apply

Summarize what will happen when you move the slider of the potentiometer from one side to another in an electric circuit.

Chapter 6

The inner structure of the potentiometer we used in this experiment is shown as *Figure 6-1*. There is a metal rod on the top from *C* to *D* whose resistance is very low and a long metal wire coiling at the bottom from *A* to *B* whose resistance is much higher. A potentiometer can be used to change current in an electric circuit. Based on the result of the experiment, you can change the resistance of the potentiometer by changing the length of the metal wire at the bottom. For the potentiometer we use in this kit, you will need to connect one of the terminals on the top (*C* or *D*) and one of the terminals on the bottom (*A* or *B*) to change the resistance of the potentiometer.

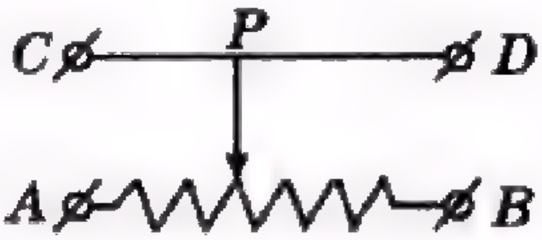


Figure 6-1

A resistor is a device designed to have a specific resistance. Resistors may be made of graphite, semiconductors, or wires that are long and thin. Sometimes, a smooth, continuous variation of the current is desired. For example, the speed control on some electric motors allows continuous, rather than step-by-step, changes in the rotation of the motor. To achieve this kind of control, a variable resistor, called a potentiometer, is used. A circuit containing a potentiometer is shown in *Figure 6-2*.

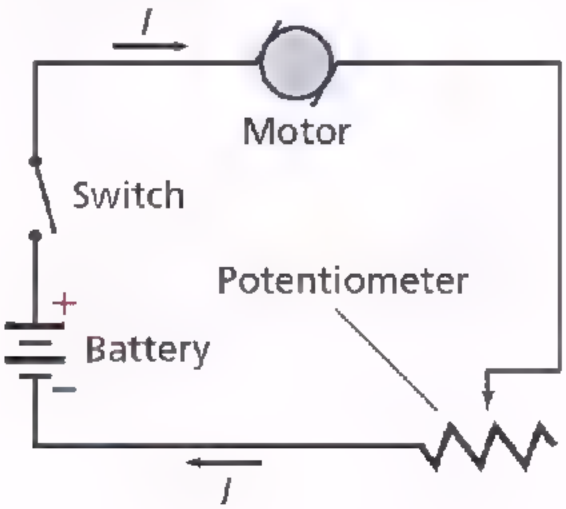


Figure 6-2

7

CHAPTER 7

Use of a voltmeter

A voltmeter is used to measure the voltage drop across a portion of a circuit. In this experiment, you will learn how to measure the voltage with a voltmeter.

QUESTIONS ***Can you measure the voltage across a lightbulb with a voltmeter?***

Objectives

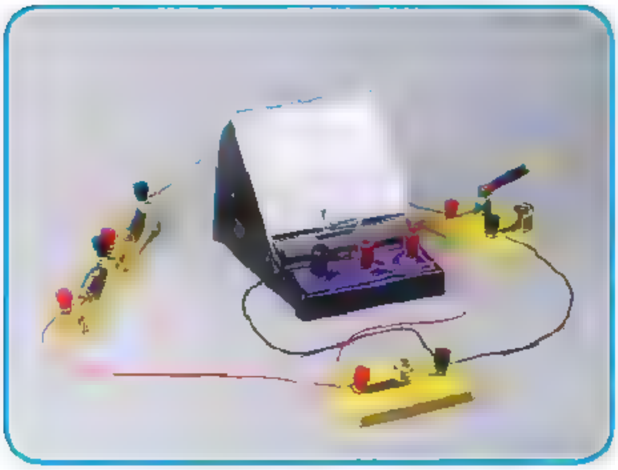
Describe how to measure the voltage in an electric circuit using voltmeter.
Describe how to read the voltage drop on a voltmeter.
Summarize the difference between using an ammeter and a voltmeter.

Precautions

Wire and lightbulbs can be hot if connected across the battery for a long time.
Make sure the pointer of the voltmeter is at zero, or you have to rotate the white screw to make it point at zero.

Materials

two Batteries	one Lightbulb	one Switch
one Ammeter	several Wires	



Procedures

Experiment A

1. Connect the positive terminal of two batteries to one terminal of a lightbulb.
2. Connect the other terminal of the lightbulb to one terminal of a switch.
   Make sure the switch is open (turned off).
3. Connect the other terminal of the switch to the negative terminal of the battery.
4. Connect one terminal of the lightbulb to the positive terminal of the voltmeter on the 3V column.
5. Connect the other terminal of the lightbulb to the negative terminal of the voltmeter.
6. **Observe** Close the switch *(turned on)* and make observations of the voltmeter.
7. **Diagram** the circuit schematic in the dashed box on the left.

Experiment B

8. Repeat the experiment by using the measure range of 15V in *step 4*. Predict what will happen on the voltmeter when the switch was closed.

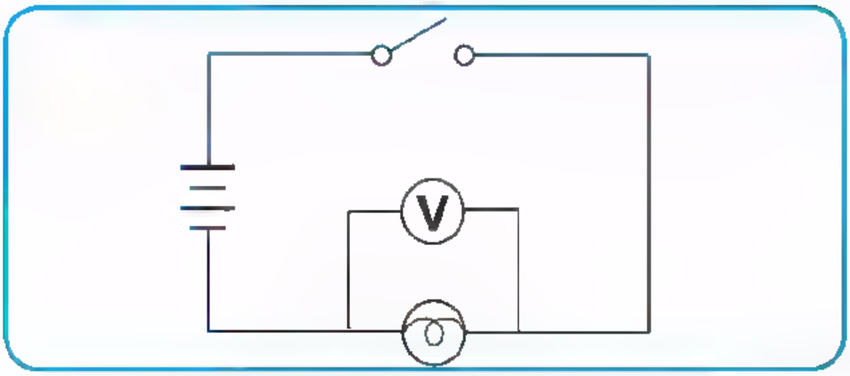
Analyzes

Recall the usage of the ammeter and try to answer the following questions.

9. What is the voltage drop across the lightbulbs in both experiments?
10. How do you read the voltage drop on a voltmeter?
11. Are the voltage drops in both experiments the same?
12. What is the difference between measuring current with an ammeter and measuring voltage with a voltmeter?

Conclude & Apply

Summarize how to use a voltmeter to measure the voltage across an element in an electric circuit.
Describe how to read the voltage drop on a voltmeter.
Summarize the difference between using an ammeter and a voltmeter.



- Difference between using an ammeter and a voltmeter.

If you want to measure the current in a current in an electric circuit, you would be required to open the current path and insert an ammeter.

If you want to measure the voltage across a component in an electric circuit, you would be required to connect both terminals of the component with a voltmeter.

In other words, the ammeter should be connected in series while the voltmeter should be connected in parallel.

What is the difference between potential difference and voltage drop?

Recall from *Chapter 1*, we knew that potential difference cause the flow of current. Voltage drop is the difference of potential between any two points. So the voltage drop is the reason of current flow.

Potential difference and the voltage drop are the same thing, but only different ways of referring to it.

The potential difference between a resistors can also be referred to as the voltage drop across the resistor or the voltage across the resistor.

- Why does the ammeter should not be connected in parallel in the circuit?

This is because the ammeter has a very small resistance.

When an ammeter with a very small resistance is connected in parallel to an appliance, little of the current will go through the appliance while almost all the current will go through the ammeter. This makes a circuit with a very low resistance and the current become very large. It is not allow because the large current may possibly get the ammeter burned, destroy the battery and even cause a fire, so the ammeter should only be connected in series in the circuit.

- Short circuit

A short circuit occurs when a circuit with a very low resistance is formed. In the case above if an ammeter is connected in parallel to an appliance, a short circuit occurs and the appliance is short-circuited. The current in a short circuit is very large because the resistance is very low. Short circuit is dangerous and it can even begin a fire.

- Why does the voltmeter should not be connected in series in the circuit?

The voltmeter has a very large resistance. When a voltmeter is connected in series to an element, because the voltmeter has a very large resistance, little of the current will go through the circuit and the appliance will not work.

CHAPTER 8

8 Basic rules in Series Circuits & Parallel Circuit

In Chapter 4, we learned that the current is the same everywhere in a series circuit
What about the current in a parallel circuit? How about the Voltage drops in a series and parallel circuit?
In this experiment, you will investigate all these question.

QUESTIONS ***What rules do the Current and Voltage Drops obey in the series circuits and the parallel circuit?***

Objectives

Describe rules that the Current and Voltage Drops obey in the *series circuits.*
Describe rules that the Current and Voltage Drops obey in the *parallel circuits*

Precautions

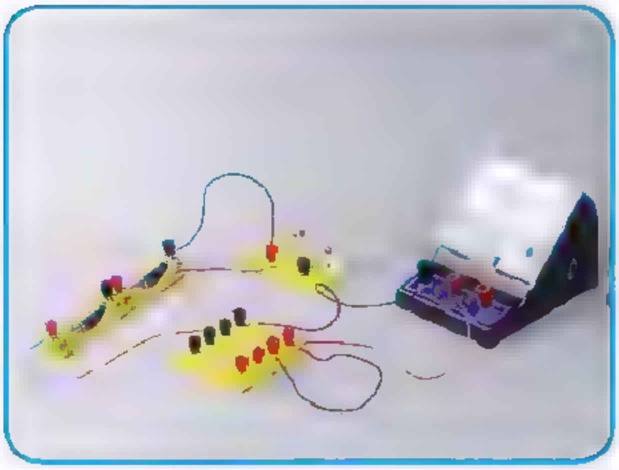
Resistors and circuits will become hot.

Materials

two 1.5-V batteries one Ammeter one Voltmeter
one 5 Ω resistor one 10 Ω resistor one Switch
some Wires

Procedures

Diagram first before you hook up any circuit.
Draw a table and record the results when you are doing the experiments.



Experiment A

1. Hook up a series circuit with two batteries, a 5-Ω resistor, a 10-Ω resistor and a switch using wires.
2. Measure the voltage drops between the 5-Ω resistor and the 10-Ω resistor once at a time and record as V_1 and V_2.
3. Measure the voltage drops between both of the resistors and record as V

Experiment B

4. Hook up a parallel circuit with two batteries, a 5-Ω resistor, a 10-Ω resistor and a switch using wires.
5. Measure the current through the 5-Ω resistor and the 10-Ω resistor once at a time and record as I_1 and I_2.
6. Measure the total current flows from the battery and record as I.

Experiment C

7. Repeat *step 4.*
8. Measure the voltage drops between the 5-Ω resistor and the 10-Ω resistor once at a time and record as V_1 and V_2
9. Measure the voltage drops between both of the resistors and record as I.

Analyzes

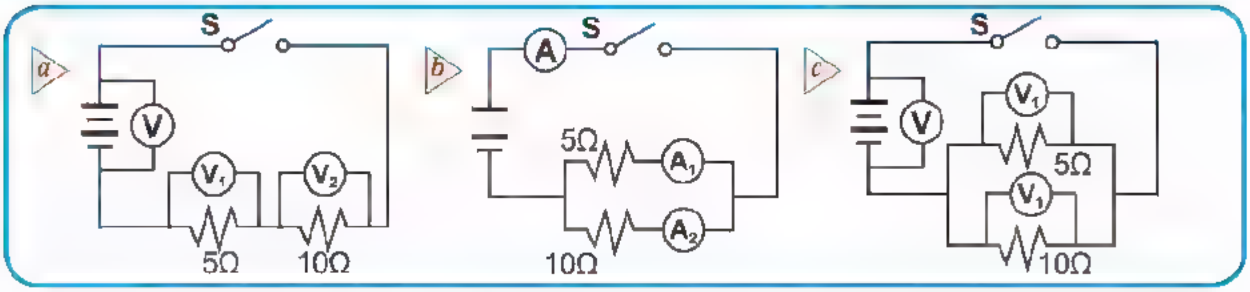
10. What is the relationship between V_1, V_2 and V in *Experiment A*?
11. What is the relationship between I_1, I_2 and I in *Experiment B*?
12. What is the relationship between V_1, V_2 and V in *Experiment C*?
13. Try to explain why the relationships exist

Conclude & Apply

Summarize the rules that the current and voltage drops obey in the series circuits and the parallel circuit

Chapter 8

Basic rules in the series circuits and the parallel circuit



Experiment	V_1	V_2	V
A			
C			

Experiment	I_1	I_2	I
B			

From *Chapter 4* and the experiments in this chapter, we've learned the current is the same everywhere in the circuit.

Rule 1: The same current flows through each part of a series circuit.

$$I = I_1 = I_2 = I_3$$

Rule 2: Voltage applied to a series circuit is equal to the sum of the individual voltage drops.

$$V = V_1 + V_2 + V_3$$

Rule 3: The sum of the currents through each path in a parallel circuit is equal to the total current that flows from the power source.

$$I = I_1 + I_2 + I_3$$

Rule 4: Voltage is the same across each component of the parallel circuit

$$V = V_1 = V_2 = V_3$$

Series	Parallel
$V_S = V_1 + V_2$ $I_S = I_1 = I_2$	$V_P = V_1 = V_2$ $I_P = I_1 + I_2$

A mountain river model is often used to help us better understand the basic rules in electric circuit.

Imagine there is only on path for the water over a waterfall. From its top on the mountains, the water flows downhill to the plains. The total drop in height does not change. Similarly, in a parallel electric circuit, the total potential difference does not change too.

Imagine there are several paths for the water over a waterfall. Some paths might have a large flow of water, while others might have a small flow. The sum of the flows, however, is equal to the total flow of water over the falls. In addition, regardless of which channel the water flows through, the drop in height is the same. Similarly, in a parallel electric circuit, the total current is the sum of the currents through each path, and the potential difference across each path is the same.

Going Further

- Equivalent Resistance

In a series circuit with two resistors, since

$$V_1 = I \cdot R_1\ ,\ V_2 = I \cdot R_2\ .$$

Therefore,

$$V = V_1 + V_2 = I \cdot (R_1 + R_2).$$

The current through the circuit is represented by the following equation.

$$I = \frac{V}{R_1 + R_2}$$

The same current would exist in the circuit with a single resistor, "R", that has a resistance equal to the sum of the resistances of the two resistors. Such a resistance is called the **equivalent resistance** of the circuit.

Equivalent Resistance for Resistors in Series $\quad R = R_1 + R_2 + \ldots$

The equivalent resistance of resistors in series equals the sum of the individual resistances of the resistors.

Current $\quad I = \dfrac{V}{R}$

Current in a series circuit is equal to the potential difference of the source divided by the equivalent resistance.

In a parallel circuit, since $I = I_1 + I_2 + I_3$, and $I_1 = \dfrac{V}{R_1}$, $I_2 = \dfrac{V}{R_2}$, $I_3 = \dfrac{V}{R_3}$,

So,
$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Equivalent Resistance for Resistors in Parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

The reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the individual resistances.

9

CHAPTER 9

Voltage, Current, Resistance

In this experiment you will investigate the mathematical relationships between voltage and current and between resistance and current. There are more than 2 variable in the experiment that is voltage, current and resistance. You will have to control all the variable except the two variable whose relationship you want to investigate. In this process you will collect data and make graphs to help you analyze

QUESTIONS ***What are the relationships between voltage and current and resistance and current?***

Objectives

Describe the relationship between voltage and theotal current flowing through a circuit through a circuit.

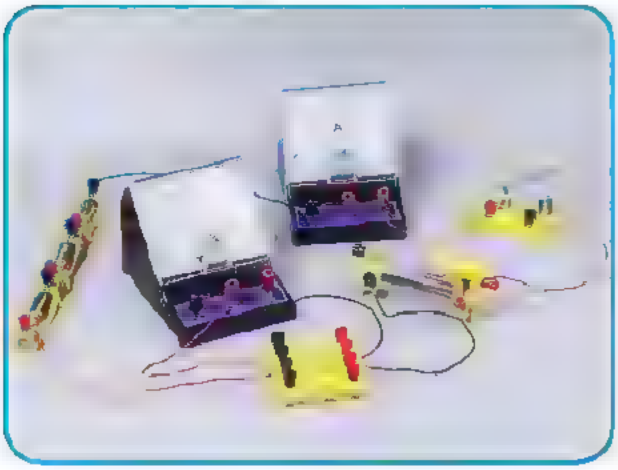
Describe the relationship between the resistance of a circuit and the total current.

Make and use **graphs** to show the relationships between current and resistance and between current and voltage.

Precautions

Resistors and circuits will become hot.

Recall from *Chapter 5* that resistance can be affected by temperature. Resistance of the resistor increases while its temperate increase, so you need to do the measurement in a short time to make sure the resistance do not change over time



Materials

three 1.5-V batteries	one Ammeter	one Voltmeter
one 5-Ω resistor	one 10-Ω resistor	one 20-Ω resistor
one Potentiometer	one Switch	Some wires

Procedures

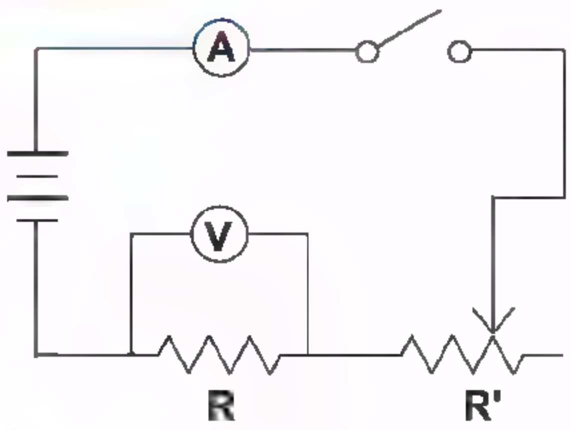


Figure 9-1

Experiment A

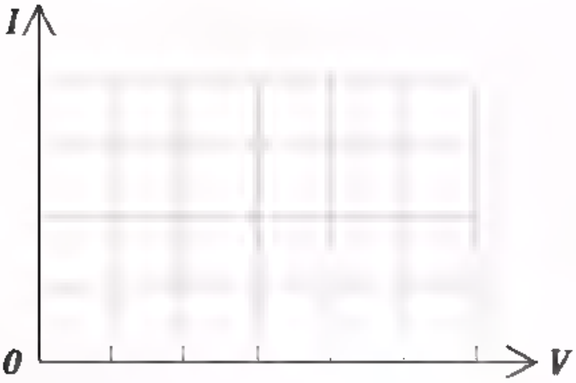
1. Hook up a circuit according to the diagram in *Figure 9-1*.
   (Using three 1.5-V batteries and a 5-Ω resistor)
2. Slide the slider of the potentiometer after close the switch.
3. Measure and record the current flowing through the resistor and voltage across it.
4. Turn off the switch.
   ⚠ Make sure you do step 2-4 in a short time to prevent the temperature of the resistor from increasing too much.
5. Repeat step 2-4 and collect data into *Data table 1*.

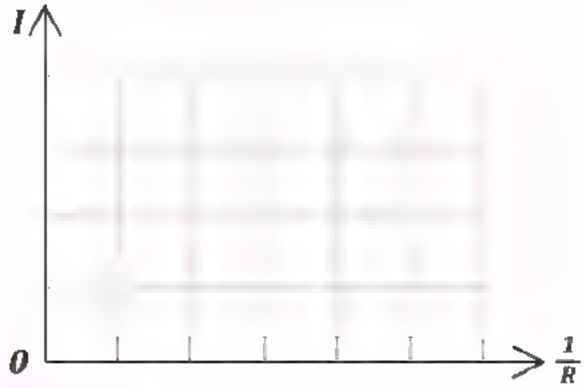
	I	*V*
1		
2		
3		
⋮		

Data Table 1

	I	*R*	$\frac{1}{R}$
1			
2			
3			
⋮			

Data Table 2





Experiment B

6. Hook up the circuit again according to the diagram in *Figure 9-1*
(Using three 1.5-V battery and a 5-Ω resistor)
7. Close the switch and slide the slider of the potentiometer so that the voltmeter shows a certain value (2.5 V, for example)
8. Measure and record the current flowing through the resistor and then turn off the switch.
⚠ Make sure you do step 7-8 in a short time.
9. Hook up the circuit again but replace the 5-Ω resistor with a 10-Ω resistor
10. Close the switch and slide the slider of the potentiometer so that the voltmeter shows the same value (2.5 V, for example)
11. Measure record the current flowing through the resistor and then turn off the switch.
12. Repeat again with a 20-Ω resistor and collect data into the *Data Table 2*.

Analyze

1. Which is the **control variable** in each of the experiment?
2. **Make and Use Graphs**
Graph the current versus the voltage. Place voltage on the x-axis and current on the y-axis.
3. **Make and Use Graphs**
Graph the current versus the reciprocal of resistance 1/R. Place the reciprocal of resistance on the *x-axis* and current on the *y-axis*

Conclude and Apply

1. Looking at the first graph that you made, how would you describe the relationship between voltage and current?
2. Why do you suppose this relationship between voltage and current exists?
3. Looking at the second graph that you made, describe the relationship between resistance and current?
4. Why do you suppose this relationship between resistance and current exists?

Chapter 9

Going Further

1. What would be the current in a circuit with a voltage of 5.0 V and a resistance of 50 kΩ? How did you determine this?
2. Could you derive a formula from your lab data to explain the relationship among voltage, current, and resistance?

Voltage, Current, and Resistance

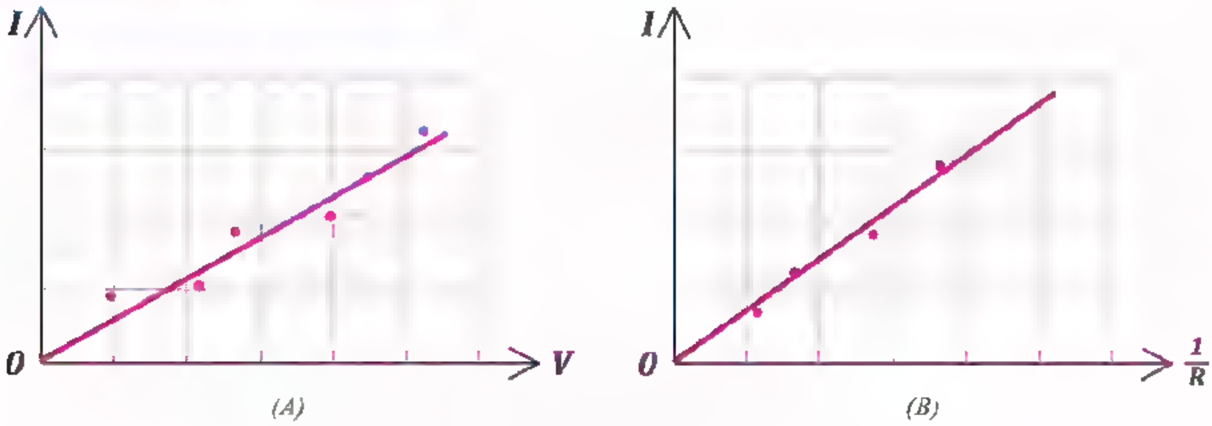


Figure 9-2
The current is proportional to the voltage(A).
The current is proportional to the reciprocal of resistance(B)

From the *Experiment A*, we can obtain some data points on a graph of current versus the voltage. Then we can draw a best-fit line through data points on the graph like it is shown in the *Figure 9-2*. There are errors in the experiment, however, we can still conclude that it should be a straight line that goes through the origin. This indicates that current is directly proportional to the voltage:

$$I \propto V$$

Current is **directly** proportional to the voltage.

From the *Experiment B*, we should also obtain a straight line that goes through the origin, which indicates that current is directly proportional to the reciprocal of resistance ***1/R***:

$$I \propto \frac{1}{R}$$

Current is directly proportional to the **reciprocal of** resistance

From both experiments, we can derive a formula that arrives at the usual mathematical equation that describes the relationship between voltage, current, and resistance:

$$I = \frac{V}{R}$$

The resistor's current ***I*** in amps (A) is equal to the resistor's voltage ***V*** in volts (V) divided by the resistance ***R*** in ohms (Ω).

In fact, this equation is one of the *Ohm's law formula.*

Ohm's law formula

When we know the voltage and the resistance, we can calculate the current.

$$I = \frac{V}{R}$$

When we know the voltage and the resistance, we can calculate the current.

$$V = I \times R$$

When we know the voltage and the resistance, we can calculate the current.

$$R = \frac{V}{I}$$

Most metallic conductors obey *Ohm's law*, at least over a limited range of voltages. Many devices such as filament lightbulbs, however, do not, that is, their relationship between current and voltage (their ***I–V*** curve) is nonlinear

Recall from *Chapter 2* that a filament lightbulb produces light as it heats up when an electric current passes through it. The resistance of a filament lightbulb will increase as the temperature of its filament increases. As a result, the current flowing through a filament lightbulb is not directly proportional to the voltage across it, in other words, current does not vary linearly

In *Figure 9-3* is the graph of current against voltage for a filament lamp. Diodes, transistors, mosfets, thyristors, etc do not obey *Ohm's law* too

In *Figure 9-4* is the graph of current against voltage for a diode. So a radio and a pocket calculator contain many devices, such as transistors and diodes, do not obey *Ohm's law*.

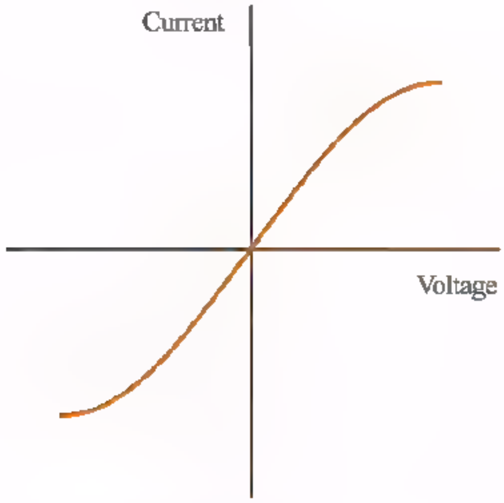


Figure 9-3
(Relationship between current and voltage for a filament lightbulb.)

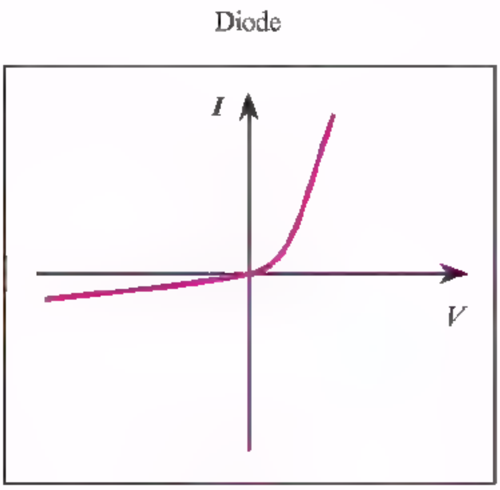


Figure 9-4
(Diodes do not obey Ohm's law.)

CHAPTER 10

10 Measurement of an Unknown Resistance by Current-Voltage Method

Recall from Chapter 9 that when we know the voltage and the current, we can calculate the resistance. In this experiment, you will learn how to measure an unknown resistance by current-voltage method.

QUESTIONS ***Given an ammeter and a voltmeter, can you measure the unknown resistance of a resistor?***

Objectives

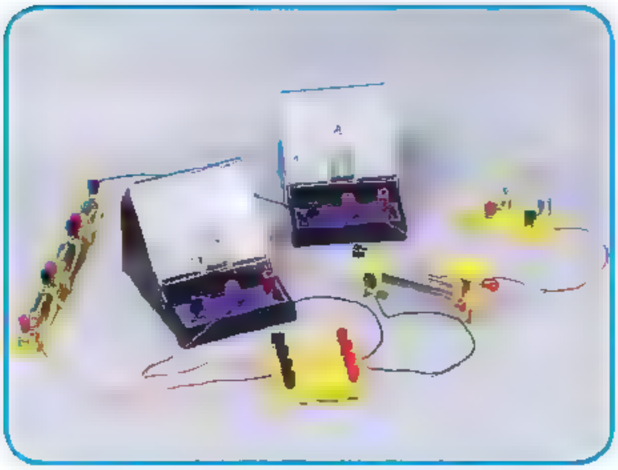
Describe how to measure an unknown resistance by current-voltage method.

Precautions

Resistors and circuits will become hot.

Materials

three 1.5-V batteries	one Ammeter	one Voltmeter
one Potentiometer	one Unknown Resistor	
one Switch	some Wires	



Procedures

1. Design a circuit and draw the diagram to measure an unknown resistor. Make sure you include a potentiometer in your circuit.

2. Design a Table to record the data.

3. Build your circuit.
4. Measure and record the lab data.
5. You'd better repeat the experiment for several time while sliding the slider of the potentiometer to get more lab data.

Analyzes

6. **Error Analysis** what factors could have affected the result of the experiment? How might the effect of these factors be reduced?
7. Why do we need more lab data?
8. Why we need to include a potentiometer in the circuit?

Conclude & Apply

Describe how to measure an unknown resistance with an ammeter and a voltmeter.

Chapter 10

Measurement of an Unknown Resistance by Current-Voltage Method

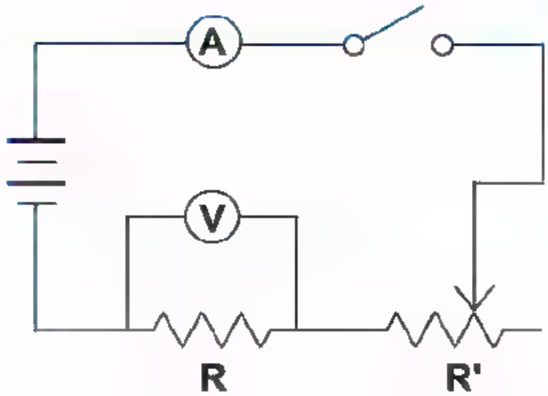


Figure 10-1
(Current-Voltage Method is also known as Ammeter Voltmeter Methods)

Using Ohm's Law, R = V/I, it is pretty easy to design the circuit and finish the measurement.
Keep it in mind that the resistance changes when the temperature changes, so make sure you close the circuit only for a short period of time.

Measuring the average of multiple sets of data is a way to reduce the error. We include a potentiometer in the circuit to change the current flowing through the unknown resistor to obtain more data.

Going Further

You may now have the close value of the unknown resistance, however, the ratio of the measured voltage and current does not give an exact value of the resistance because of the resistance of the meters.

The voltmeter is a high resistance instrument and draws little current as long as the voltmeter resistance R_V is much greater than R. Thus,

$$R \cong \frac{V}{I} \quad (\text{if } R_V > R)$$

We can simplify problems by introducing the idealized model like these when we begin learning the basic physics

For a more accurate measurement, the resistance of the voltmeter must be taken into account. The current drawn by the voltmeter is $I_V = V/R_V$ and the total current measured by the ammeter is

$$I = I_R + I_V$$

The true current through the resistance is $I_R = I - I_V$

$$I_R = I - I_V$$

and from *Ohm's Law* $\quad R_{exact} = \frac{V}{I_R} = \frac{V}{I - I_V} = \frac{V}{I - V/R_V}$

Chapter 10

Another circuit is shown in *Figure 10-2.*

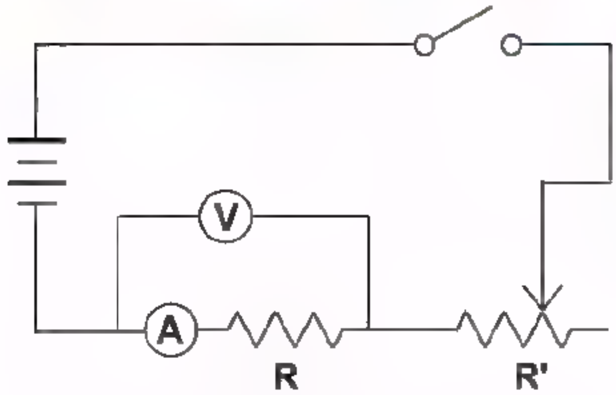


Figure 10-2

In this case, the ammeter measures the current through the resistance alone, but the voltmeter measures the voltage drop across both the resistance and the ammeter. Since the ammeter is a low resistance instrument, then the voltage drop across the ammeter ($V_A = I \cdot R_A$) is small compared to that across R. Then

$$R \cong \frac{V}{I} \quad (\, if \; R_A > R \,)$$

R_A is the resistance of the ammeter

If the resistance of the ammeter is taken into account, then

$$V = V_R + V_A$$

$$= I \cdot R_{exact} + I \cdot R_A$$

$$= I \cdot (\, R_{exact} + R_A \,)$$

$$= I \cdot R'$$

Where $\quad R' = R_{exact} + R_A$

Since $\quad R' = \dfrac{V}{I}$

then $\quad R_{exact} = R' - R_A$

$$= \frac{V}{I} - R_A$$

Critical thinking

Which circuit should I build when I measure a resistor with large resistance?

If you build the circuit in *Figure 10 1*. The resistance value you measure is the Equivalent resistance of the R_V and the unknown resistor in parallel. Because the voltmeter measures the voltage across the parallel part and the ammeter measure the current flowing through the parallel part too.

Recall from *Chapter 8* then we have the following equation:

$$R_{measure} = \frac{R_{exact} \cdot R_V}{R_{exact} + R_V}$$

$$= \left(\frac{R_V}{R_{exact} + R_V} \right) \cdot R_{exact}$$

The relative error:

$$\delta = \left| \frac{R_{measure} - R_{exact}}{R_{exact}} \right|$$

$$= \frac{R_{exact}}{R_{exact} + R_V}$$

If you build the circuit in *Figure 10-2*. The resistance value you measure is the equivalent resistance of the R_A and the unknown resistor in series. Because the voltmeter measures the voltage across the series part and the ammeter measure the current flowing through the through series part too.

$$R_{measure} = R_{exact} + R_A$$

The relative error:

$$\delta' = \left| \frac{R_{measure} - R_{exact}}{R_{exact}} \right|$$

$$= \frac{R_A}{R_{exact}}$$

MAGNETISM

CHAPTER 11

11 Magnetic Field

You may have observed some effects of magnetism by playing with a magnet In this Chapter, you will learn about the general properties of magnets.

QUESTIONS ***What is the general properties of magnets?***

Objectives

Describe the properties of magnets
Compare and contrast various magnetic fields.

Precautions

Scissors and nails are sharp and can cause injury.

Materials

one Bar Magnet
one Horseshoe Magnet
one Compass
one Iron Filings Box

Procedures

1. Place a compass on a horizontal surface, make observation on the needle of the compass when it is still.
2. Move the *North Pole* and the *South Pole* of the bar magnet towards each pole of the horseshoe magnet and make observation on the horseshoe magnet.
3. Rub a piece of magnet with an object made of iron like a pair of scissors or a nail. Then move the object towards some paper clips made of iron. Make observation on the paper clips
4. Place a compass around a bar magnet or horseshoe magnet. Change the position of the compass around the magnet Make observation on the compass.

Analyzes

5. Which direction does the red terminal of the pointer point to? What about the white one?
6. What rules can you tell from the *step 2*?
7. The needle in the compass is a magnet itself. With a bar magnet, can you tell whether the red terminal of the needle is the *North Pole* or the *South Pole*?
8. Why does the needle turn when its position changes? Try to explain

Conclude & Apply

Describe the properties of magnets

Chapter 11

Magnets

All magnets have two poles, one called the *North Pole* and one called the *South Pole*. Like poles repel and unlike polls attract (in analogy to positive and negative charges in electrostatics). North and South poles always exist in pairs, if one were to split a permanent magnet in half, two smaller magnets would be created, each with a *North pole* and *South pole* (Although some scientists have predicted the existence of monopole, no monopole has been found yet).

Knowing that magnets always orient themselves in a north south direction, it may occur to you that Earth itself is a giant magnet Because opposite poles attract and the north pole of a compass magnet points north, the south pole of the Earth magnet must be near Earth's geographic north pole.

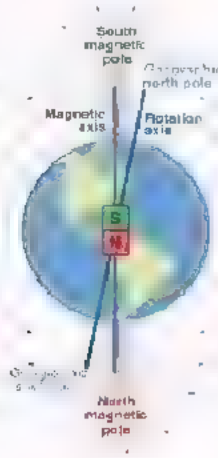


Figure 11-1

(The shape of Earth's magnetic field is similar to that of a huge bar magnet tilted about 11° from Earth's geographic north and south poles.)

Figure 11-2

(The nail become polarized by the magnetic field of the horseshoe magnet.)

When a magnet touches a nail, smaller metal pieces can be attracted to the nail, as shown in *Figure 11-2*. The nail itself becomes a magnet which causes the nail to become polarized. If you pull away the magnet, the nail loses some of its magnetization and will no longer exhibit as much attraction for other metal objects.

If you touch a magnet to a piece of soft iron (iron with a low carbon content) replacing the nail, after you pull away the magnet, the iron loses all of its attraction for the other metal objects. This is because soft iron is a **temporary magnet**

Permanent magnets

The magnetism of permanent magnets is extremely strong and it is very difficult to lose. This is determined by the microscopic structure of the material Many permanent magnets are made of an iron alloy called ALNICO V, which contains a mix of aluminum, nickel, and cobalt. Compare with the soft iron and the permanent magnets like the bar magnet, a nail has other material in it which allows it to retain some of its magnetism when a permanent magnet is pulled away.

Chapter 11

Magnetic Fields Around Permanent Magnets

Place a bar magnet or the horseshoe magnet on the iron filings box. Just like a tiny compass needle, the iron filing rotates until it is parallel to the magnetic field. In this way, you can visualize the magnetic field.

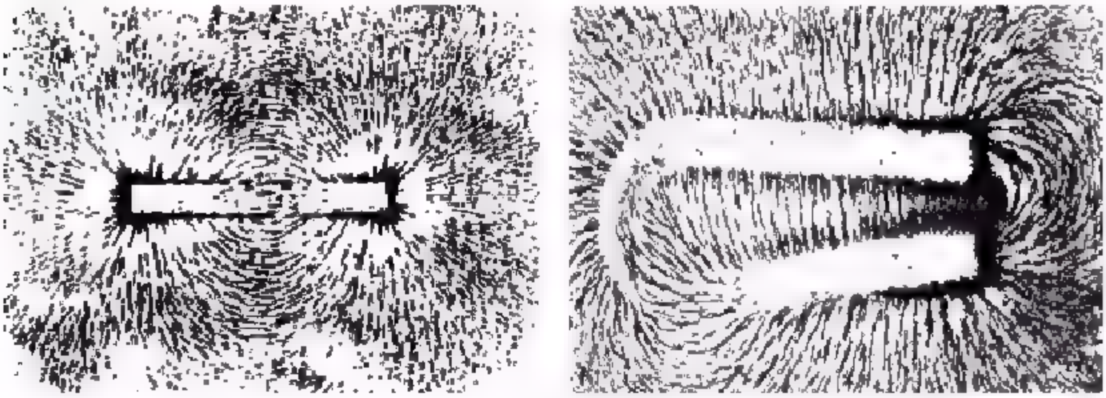


Figure 11-3
(Each tiny magnetic iron filing is a tiny magnet with a north and south pole just like a tiny compass.)

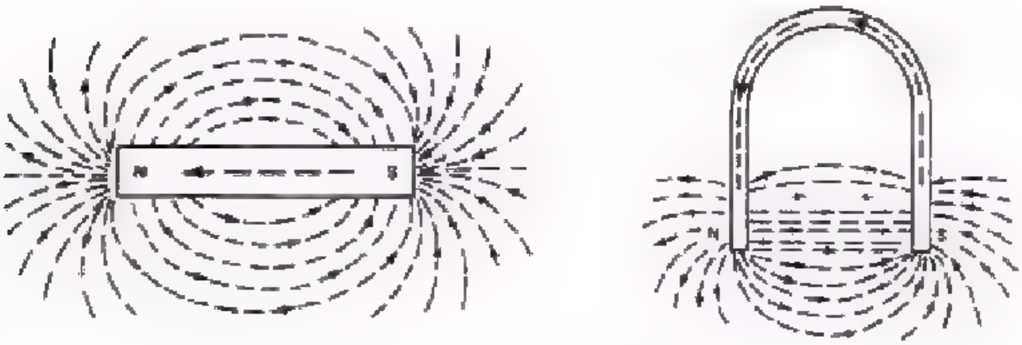


Figure 11-4
(Magnetic field lines of bar magnets and horseshoe magnets.)

Magnetic Fields Lines

Magnetic field lines don't start or stop anywhere, they always make closed loops and will continue inside a magnetic material (though sometimes they are not drawn this way).

By convention, the field direction is taken to be outward from the North Pole and in to the South Pole of the magnet.

Magnetic field lines also provide a measure of the strength of the magnetic field. The number of magnetic field lines passing through a surface is called the magnetic flux. The flux per unit area is proportional to the strength of the magnetic field

The magnetic field is strongest where the field lines are most concentrated.

As can be visualized with the magnetic field lines, the magnetic field is strongest inside the magnetic material. The strongest external magnetic fields are near the poles.

12

CHAPTER 12

Magnetic Effect of Electric Current

Electricity and magnetism are very closely related. The study of both and how they are connected, is called ***electromagnetism*** *In this chapter you will learn about the effect of current on magnetic field*

QUESTIONS ***How flowing current affects the compass?***

Objectives

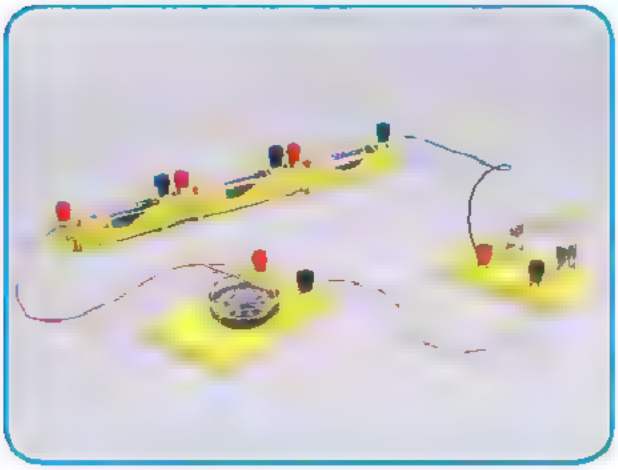
Describe the how flowing current affects the magnetic field.

Precautions

In this experiment, you will need to short circuit the batteries to produce a large current. DO NOT keep the batteries short circuited for a long time. Conductors and batteries will heat up.

Materials

three 1 5-V batteries	one Double Rail Module
one Copper Rod	one Switch
one Compass	some Wires



Procedures

1. Hook up a circuit with three 1.5-V battery, a double rail module and a switch using wires. Make sure the switch is open.
2. Put a copper rod over the double rail module.
3. Put a compass under the copper rod.
4. Close the circuit for a very short period of time.
5. Observe Make observations of the compass.
6. Open the switch
7. Repeat the experiment after reversing the direction of the current.

Analyzes

8. What happen to the compass when there is current flowing through the copper rod?
9. What happened to the compass after the switch was open on step 6?
10. Was there any difference between the result on step 5 and step 7?

Conclude & Apply

Summarize how flowing current affects the magnetic field?

Chapter 12

Electromagnetism

While preparing for an evening lecture on 21 April 1820, *Hans Christian Oersted*, a Danish scientist, made a surprising observation. As he was setting up his materials, he noticed a compass needle deflected away from magnetic north when the electric current from the battery he was using was switched on and off.

Figure 12-1
(Oersted was demonstrating his discovery.)

Figure 12-2
(The magnetic field produced by the current in a wire through a cardboard disk shows up as concentric circles of iron filings around the wire.)

Figure 12-3
(Using compass to show the direction of magnetic field of a current-carrying wire.)

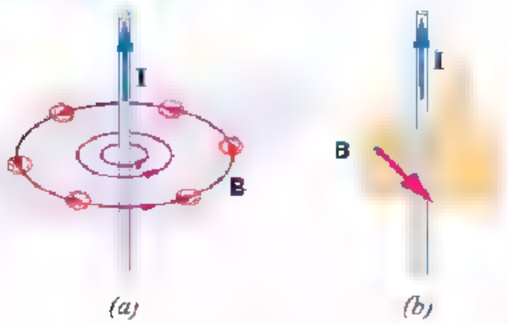


Figure 12-4
(The first right-hand rule for a straight, current-carrying wire shows the direction of the magnetic field.)

Magnetic field near a wire loop

Applying the first right-hand rule to determine the direction of the magnetic field produced by a current-carrying wire loop, you can find that all parts of the loop contribute magnetic field in the same direction inside the loop, as shown in *Figure 12-5*. The magnetic field is more concentrated in the center of the loop than outside the current-carrying loop.

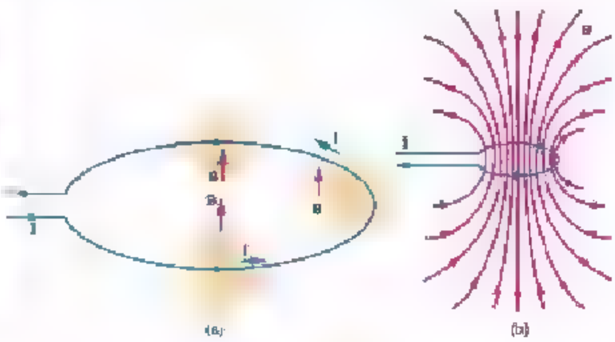


Figure 12-5
(The first right-hand rule can also apply to a wire loop.)

As shown in the *Figure 12-6*, coils made with multiple loops is called a solenoid, which produces a stronger magnetic field.

A current-carrying coil has a field similar to a permanent magnet. When it is brought close to a bar magnet, one end of the coil attracts the north pole of the magnet. Thus, the current-carrying coil has a north and a south pole and is itself a magnet. This magnet, which is created when current flows through a wire coil, is called an electromagnet.

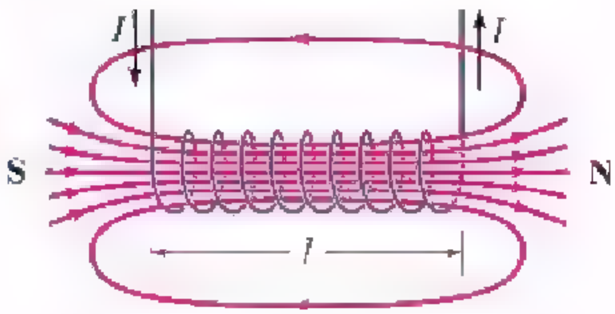


Figure 12-6
(Magnetic field near a coil.)

CHAPTER 13

13 Electromagnet

In this experiment, you will investigate the factors that impact the strength of the magnetic field of the electromagnet

QUESTIONS ***What factors impact the strength of the magnetic field of an electromagnet?***

Objectives

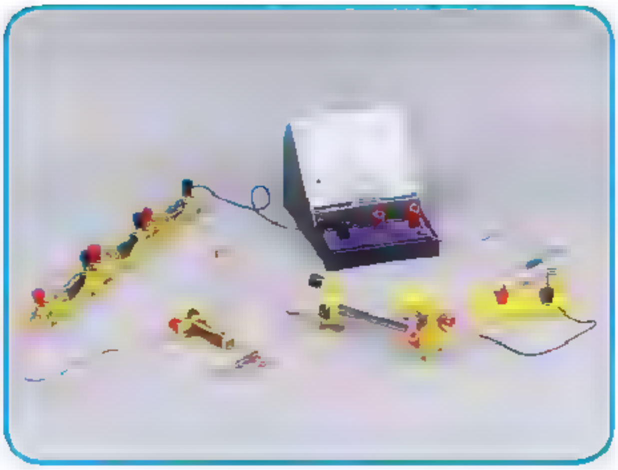
Define electromagnet
Describe factors that impact the strength of the magnetic field of the electromagnet.

Precautions

Solenoid and circuits will become hot.

Materials

three 1.5-V batteries	one Solenoid	one Switch
one Potentiometer	one Ammeter	some Wires
some Paper Clips		



Procedures

1. Hook up a circuit while the switch is open as it is shown in picture.
2. Put a bunch of paper clips on the desk.
3. Close the switch and record the number of the paper clips attracted by the solenoid.
4. Repeat step 1~3 after taking away the iron core of the solenoid.

Analyzes

5. What can you tell from the result of the experiment?
6. Do you think the strength of the current impact the strength of the magnetic field of the solenoid? Test your hypothesis
7. What else factors do you think that impact the strength of the magnetic field of the solenoid? Try to explain.

Conclude & Apply

Summarize the factors that impact the strength of the magnetic field of the electromagnet.

Go Further

Design experiments and investigate the relationship between the direction of the magnetic field and the direction of the current. Try to explain with right-hand rule.

Chapter 13

Electromagnet

An electromagnet is a type of magnet in which the magnetic field is produced by an electric current. The magnetic field disappears when the current is turned off. Electromagnets usually consist of insulated wire wound into a coil. A current through the wire creates a magnetic field which is concentrated in the hole in the center of the coil. The wire are often wound around a magnetic core like iron; the magnetic core concentrates the **magnetic flux** and makes a more powerful magnet.

Figure 13-1
(You can make a electromagnet by winding wire around a nail and connecting it to a battery.)

Figure 13-2
(Electromagnets are used to move the steel in the factory.)

The magnetic field produced by each loop of the electromagnet is the same. Because these fields are in the same direction, increasing the number of loops increases the strength of the magnetic field, on the other hand, increasing the current going through the wire increases the strength of the magnetic field of each loop and thus also increases the strength of the magnetic field of the entire electromagnet.

The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be quickly changed by controlling the amount of electric current in the winding. However, unlike a permanent magnet that needs no power, an electromagnet requires a continuous supply of current to maintain the magnetic field.

Electromagnets are widely used as components of other electrical devices, such as motors, generators, relays, loudspeakers and hard disks. Electromagnets are also employed in industry for picking up and moving heavy iron objects such as scrap iron and steel.

The second right-hand rule is a method you can use to determine the direction of the field produced by an electromagnet relative to the flow of conventional current. Imagine holding an insulated coil with your right hand. If you then curl your fingers around the loops in the direction of the conventional (positive) current, as in *Figure 13-3*, your thumb will point toward the north pole of the electromagnet.

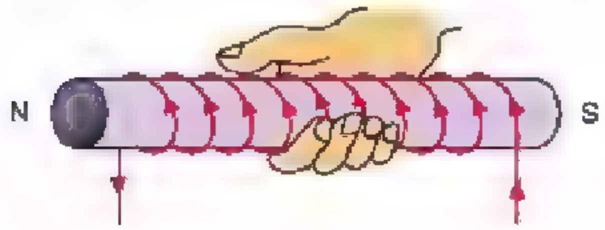


Figure 13-3
(The second right-hand rule is used to determine the direction of the field produced by an electromagnet.)

14

CHAPTER 14

Forces on Currents in Magnetic Fields

Recall in Chapter 12 that a current carrying conductor has magnetic field around it. If we put a permanent magnet near the conductor, the magnetic field around the current carrying conductor can interact with the existing magnetic field of the permanent magnet, causing a force on the wire. In this experiment we will investigate the forces on currents in magnetic fields

QUESTIONS ***How to determine the force's direction that the magnetic field exert on the current carrying conductor?***

Objectives

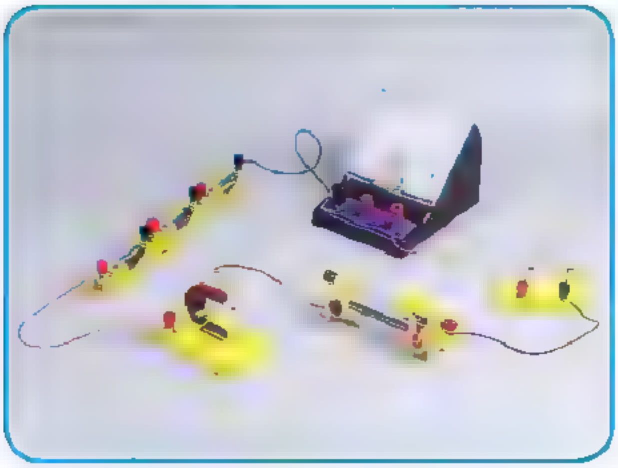
Define the force's direction that the magnetic field exert on the current carrying conductor.

Precautions

Copper rod and circuits will become hot.

Materials

three 1.5-V batteries
one Double-rail Module
one Switch
one Ammeter
one Copper Rod
one Horseshoe Magnet
one Potentiometer
some Wires



Procedures

1. Put a horseshoe magnet between the rails on a double rail module.
2. Put a copper rod between the two poles of the horseshoe magnet on the rails.
3. Hook up a circuit while the switch is open as it is shown in the picture.
4. Close switch and make observation on the copper rod.
5. Repeat step 1 ~ 4 while you changing the strength of the current
6. Repeat step 1 ~ 4 while you changing the direction of the current.
7. Repeat step 1 ~ 4 while you changing the direction of the magnetic field caused by the horseshoe magnet.

Analyzes

8. What happens before and after the current reach a certain strength? Explain.
9. What happen when you change the direction of the current?
10. What happen when you change the direction of the magnetic field?
11. Try to explain the result in step 2 and step 3 with right-hand rule.

Conclude & Apply

Summarize the force's direction that the magnetic field exert on the current carrying conductor.

Chapter 14

Forces on Currents in Magnetic Fields

In the experiment, we found that the copper rod will move when the current reach a certain strength. This is because a force will be exerted on a current when it is put in a magnetic field. When the current become larger, the force will be strong enough to overcome the friction then the copper rod begin to move. When the direction of the current changes, the copper rod moves to the opposite direction When the direction of the magnetic field changes the moving direction of the copper rod changes correspondingly too.

The direction of the force on a current-carrying wire in a magnetic field can be found by using the third right-hand rule. Point the fingers of your right hand in the direction of the magnetic field, and point your thumb in the direction of the current in the wire. The palm of your hand will be facing in the direction of the force acting on the wire.

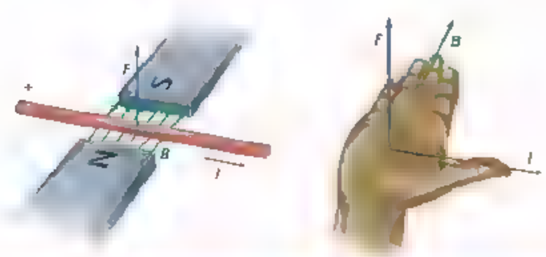


Figure 14-1 (The third right-hand rule)

Experiments show that the magnitude of the force, F, on the wire, is proportional to the strength of the field, B, the current, I, in the wire, and the length, L, of the wire in the magnetic field. The relationship of these four factors is as follows.

Force on a Current-Carrying Wire in a Magnetic Field $F = I \cdot L \cdot B$

The force on a current carrying wire in a magnetic field s equal to the product of magnetic field strength, the current, and the length of the wire

The strength of a magnetic field, B, is measured in Teslas, T. $1\ T$ is equivalent to $1\ N/Am$.

Galvanometer

The forces exerted on a loop of wire in a magnetic field can be used to measure current. As shown in *Figure 14-2*, if a small loop of current-carrying wire is p aced in the strong magnetic field of a permanent magnet, applying the third right-hand rule, we can find that one side of the loop is forced down, while the other side of the loop is forced up.

As a result, the loop rotates. This principle is used in a galvanometer A galvanometer is a device used to measure very small currents, and therefore, it can be used as a voltmeter or an ammeter

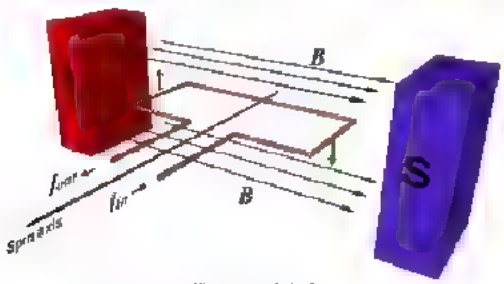


Figure 14-2
(A current-carrying wire loop will rotate in a magnetic field.)

Figure 14-3
(Principle of the galvanometer)

CHAPTER 15

15 Electric motors

In this chapter you will learn about the working principle of electric motor.

QUESTIONS ***Can you get an electric motor work?***

Objectives

Get an electric motor work

Precautions

Keep your hands away from the motor in case that the rotating motor may hurt you.

Materials

three 1.5-V batteries
one Electric Motor model
one Switch
two Permanent Magnets
one Fan Blade
some Wires

Procedures

1. Insert two permanent magnets on both side of the electric motor.
2. Connect three 1.5-V batteries in series.
3. Connect one terminal of the power supply with one terminal of a switch.
4. Connect the other terminal of the switch with one terminal of the electric motor model.
5. Connect the other terminal of the electric motor model with the other terminal of the power supply.
6. Close the switch.
7. Observe make observation on the motor
8. Repeat step 1 ~ 7 after inserting two permanent magnets between the motor.

Analyzes

9. Does the motor work? If it does, recall from *Chapter 14*, try to explain its principle
10. If the motor failed to work, try to change the direction of magnetic field by flipping the permanent magnets.
11. Can the electric motor work without permanent magnets?

Conclude & Apply

Summarize the principle that the motor apply to work.

Chapter 15

Going Further

Replace the magnets with a horseshoe magnet and make the motor work.

Electric motors

You have seen how the simple loop of wire used in a galvanometer cannot rotate more than 180°. The forces push the right side of the loop up and the left side of the loop down until the loop reaches the vertical position. The loop will not continue to turn because the forces are still up and down, now parallel to the loop, and can cause no further rotation.

How can you allow the loop to continue to rotate?

The current through the loop must reverse direction just as the loop reaches its vertical position. This reversal allows the loop to continue rotating, as illustrated in *Figure 15-1*. To reverse current direction, an electric connection is made between contacts, called brushes, and a ring that is split into two halves, called a split-ring commutator. Brushes make contact with the commutator and allow current to flow into the loop. As the loop rotates, so does the commutator. The split ring is arranged so that each half of the commutator changes brushes just as the loop reaches the vertical position. Changing brushes reverse the current in the loop.

As a result, the direction of the force on each side of the loop is reversed, and the loop continues to rotate. This process repeats at each half-turn, causing the loop to spin in the magnetic field. The result is an electric motor, which is an apparatus that converts electric energy into rotational kinetic energy.

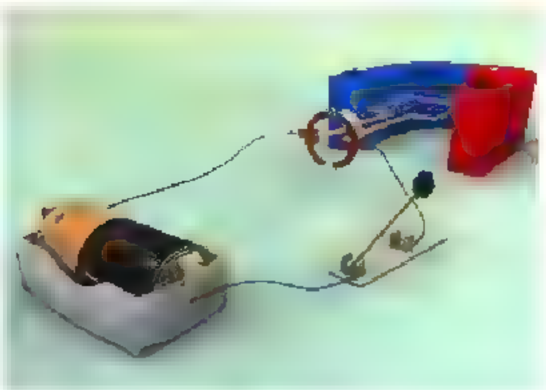


Figure 15-1

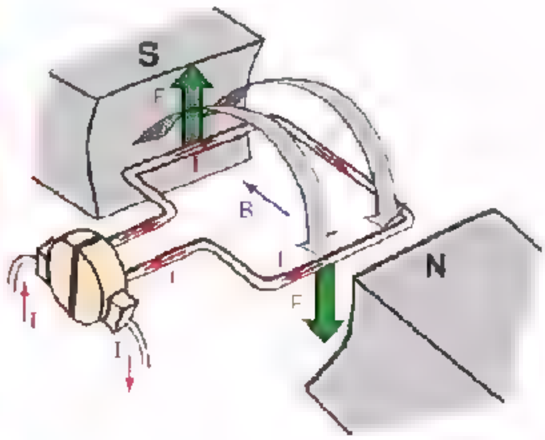


Figure 15-2

CHAPTER 16

16 Electric Generators

In this chapter you will learn about the working principle of electric generators.

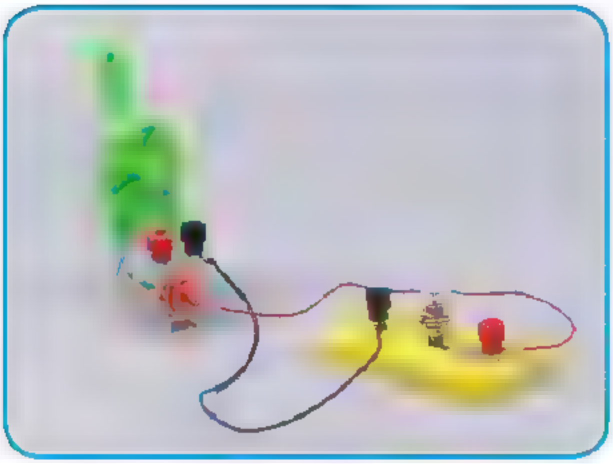
QUESTIONS ***Can you get a lightbulb to light with a motor?***

Objectives

Get a lightbulb to light with a motor

Materials

one Electric Motor
one Lightbulb Socket
one Lightbulb
one Crank Device
one Switch
some Wires



Procedures

1. Put the electric motor into the crank device
2. Connect one terminal of the lightbulb with one terminal of a switch.
3. Connect the other terminal of the switch with one terminal of the electric motor.
4. Connect the other terminal of the electric motor with the other terminal of the lightbulb.
5. Crank the motor with your hands.
6. **Observe**. Make observation on the lightbulb.

Going Further

Connect the electric motor with an ammeter in series directly, then crank the motor. See whether the direction you crank affects the direction of the current.

Chapter 16

Electromagnetic Induction

In the experiment as shown in *Figure 16-1*, Faraday found that when the wire is held stationary or is moved parallel to the magnetic field, there is no current, but when the wire moves up or down through the field the current will be generated An electric current is generated in a wire only when the wire cuts magnetic field lines.

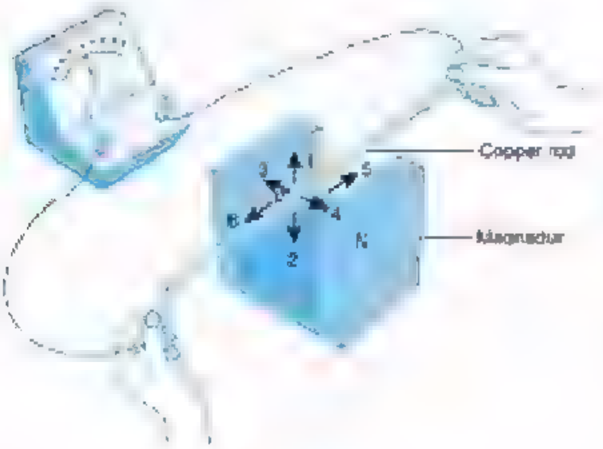


Figure 16-1
(Cutting the magnetic field lines can produce electric current.)

Faraday also found that not only the current will be generated when the conductor move through a magnetic field but also when a magnetic field move past the conductor. The process of generating a current by the relative motion between the wire and the magnetic field is called *electromagnetic induction.*

We can use the fourth right-hand rule to determine the direction of the current. Hold your right hand so that your thumb points in the direction in which the wire is moving and your fingers point in the direction of the magnetic field. The palm of your hand will point in the direction of the current, as illustrated in *Figure 16-2*.

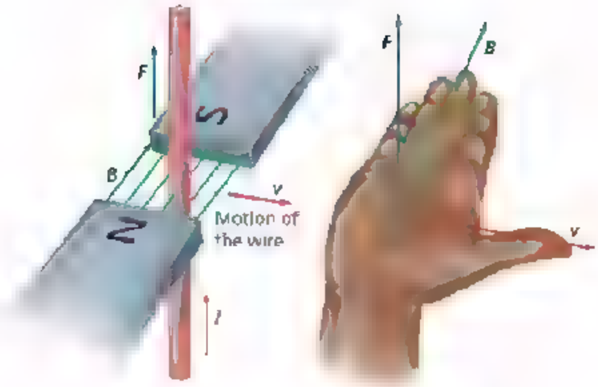


Figure 16-2
(The fourth right-hand rule.)

Electric Generators

The electric generator, invented by *Michael Faraday*, converts mechanical energy to electrical energy. An electric generator consists of a number of wire loops placed in a strong magnetic field, which is similar to the electric motor. When the wire loops rotates, it cuts magnetic field lines. So the current is generated in a circuit.

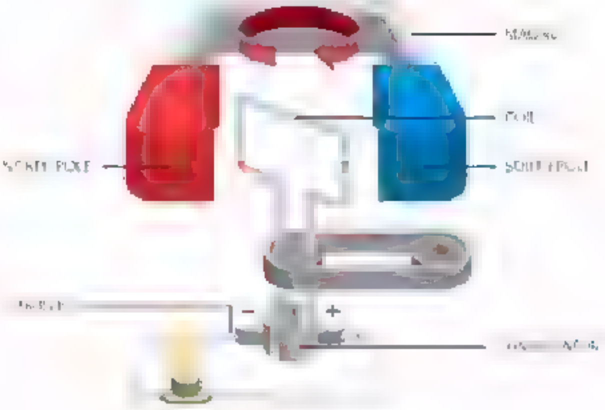


Figure 16-3
(An electric current is generated in a wire loop as the loop rotates.)

CHAPTER 17

17 Fruit Battery

In this experiment, you will make a battery with fruits and learn about the principle of the wet cell battery

QUESTIONS ***Can you make a battery with Fruits?***

Objectives

Make a Fruit Battery

Precautions

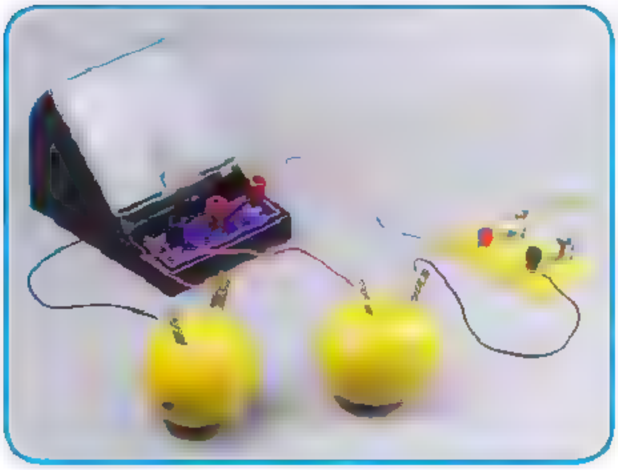
The fruits used in this project should not be eaten. Care should be taken when handling the metal electrodes which are sharp and may cut skin.

Materials

Fruits (such as lemons, oranges and tomatoes.)
one Voltmeter two Copper and Zinc Electrodes
some Wires

Procedures

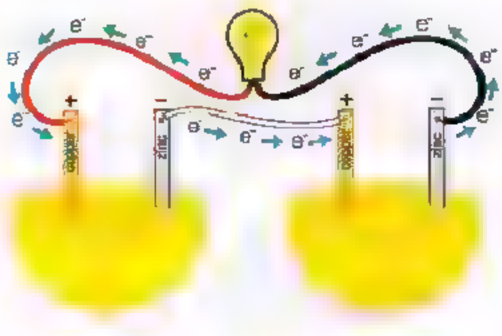
1. Stick the zinc electrode all the way into a piece of fruit to be tested.
2. Place the copper electrode on the opposite side of the fruit.
3. Connect them to the voltmeter
4. Make observation on the voltmeter



Wet cell battery

When two dissimilar metals are placed in a common conducting solution, electricity will be produced. This is the basis of the electro-chemical cell, or wet cell. In the early nineteenth-century, Alessandro Volta used this fact of physics to invent the voltaic pile and discovered the first practical method of generating electricity Constructed of alternating discs of zinc and copper metals with pieces of cardboard soaked in a salt solution between the metals, his voltaic pile produced an electrical current. Alessandro Volta's voltaic pile was the first "wet cell battery" that produced electricity.

A wet cell consists of a negative electrode, a positive electrode and an electrolyte, which conducts ions (atoms with an electric charge). In this science fair project, copper and zinc metals will be used as the electrodes and the citric acid found in fresh fruit is the electrolyte. The chemistry behind the fruit cell is that zinc is more reactive than copper which means zinc loses electrons more easily than copper. As a result, oxidation occurs in the zinc metal strip and zinc metal loses electrons which then become zinc ions. The electrons then flow from the zinc strip to the copper strip through an external circuit. In the copper strip, reduction occurs and the hydrogen ions in the fruit's critic acid juice accept these electrons to form hydrogen gas, this explains why the investigator may observe bubbling of gas produced at the copper strip when the two metals are connected by a wire.



CHAPTER 18
18 Building an Electric Bell

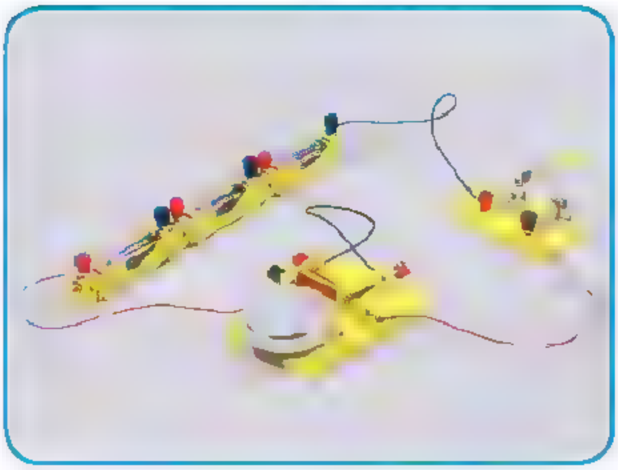
QUESTIONS ***Can you build an electric bell?***

Objectives

Build an electric bell.

Materials

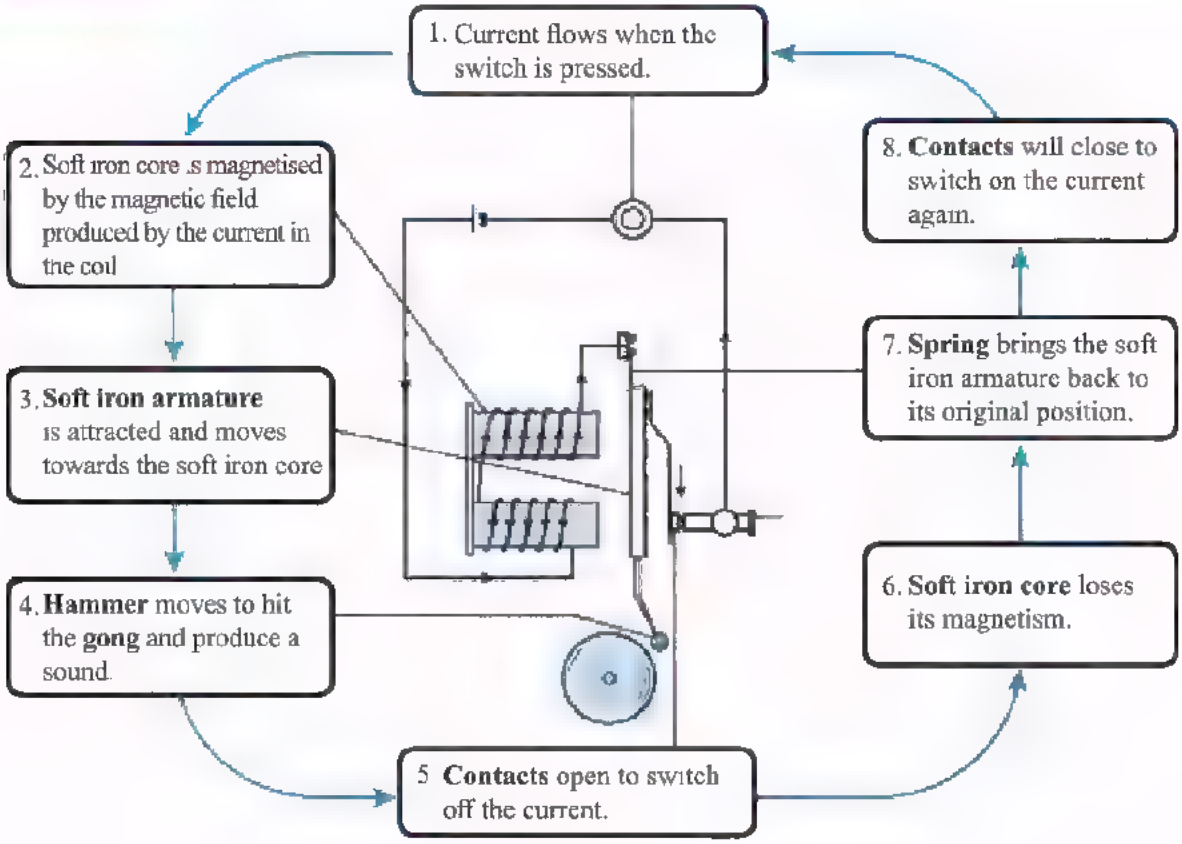
three 1.5-V Batteries
one Electric Bell Model
some Wires
one Solenoid
one Switch



Procedures

1. Hook up a circuit while the switch is open as it is shown in picture.
2. Close the switch and make observation on the bell.

Electric Bell



COMPONENT

Voltmeter

Ammeter

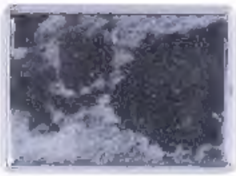
Motor

Wires

Screwdriver

Hand Crank

Compass



Iron filings box

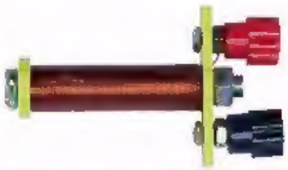
Horseshoe Magnet

Bar Magnet

Permanent Magnet

Lightbulb

Potentiometer



Solenoid

Zinc electrode

Copper electrode

Double Rail Module

Battery Holder

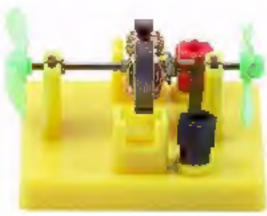
Resistor Module

Stand (circle magnets)

Electric Bell Model

Switch

Switch



Electric Motor Model

Experiment Manual

by LERBOR